Opportunities for Dust & Loess Observations to Improve Models

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(On the Web at http://dust.ess.uci.edu/ppr/smn_dst_obs.pdf)

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Abstract

We need more observations.

1. Overview

1. Generic model problems
2. Supply-limited environments
3. Reflectance-based erodibility
4. Loess as a dust proxy
5. Sensor Networks

2. Generic Model Problems

Emissions Estimates:

1. Global emission estimate range is *narrower* than burden estimate range
   (a) Mobilization fluxes are measured in situ, not from satellite
   (b) Satellite data should provide much better constraints on burden than emission
   (c) Transport and deposition processes should compound emissions uncertainties
   (d) Many processes are not represented or represented crudely
2. What proxies can be used to improve emissions estimates?

Table 1: **Present Climate Dust Budget Estimates**[a]

Reference	E $\mathrm{Tg\,yr^{-1}}$	τ Days	M Tg
Duce et al. [1991]	(910)		
Tegen and Fung [1994]	3000		
Tegen and Fung [1995]	1222	5.6	18.8
Andreae [1996]	1500	4	8.4
Prospero [1996]	(358)		
Mahowald et al. [1999]	3000		
Penner et al. [2001]	2150		
Ginoux et al. [2001]	(478) 1814	7.1	35.9
Chin et al. [2002]	1650	6.3	28.7
Werner et al. [2002]	1060 ± 194	2.8 ± 0.5	8 ± 3
Tegen et al. [2002]	1100	7.4	22.2
Zender et al. [2003a]	(314) 1490 ± 160	4.3 ± 1.0	17.4 ± 2
Luo et al. [2003]	1654	5.1	23
Mahowald and Luo [2003]	1654	5.1	23
Miller et al. [2003]	1018	5.2	14.6
Tegen et al. [2004]	1921		

[a]Shown are annual emissions E [$\mathrm{Tg\,yr^{-1}}$], atmospheric turnover time τ [d], and atmospheric burden M [Tg]. Estimates of deposition to oceans are parenthesized. Order is chronological.

3. Supply-Limited Environments

Many models use "separation of constraints"

$$F_\mathrm{d} \propto A_\mathrm{m} S u_*^3 \tag{1}$$

$$A_\mathrm{m} = (1 - A_\mathrm{w})(1 - A_\mathrm{s})(1 - A_\mathrm{V}) \tag{2}$$

where F_d [$\mathrm{kg\,m^{-2}\,s^{-1}}$] is dust vertical mass flux, A_m is bare ground fraction, and S is erodibility factor. Could implement supply-limited constraints as an additional erodibility factor:

$$S = S_\mathrm{s} \times S_\mathrm{c} \tag{3}$$

where S_s is the sediment supply constraint and S_c is the crustal constraint.

- Need global maps of supply limitation factors S_s, S_c
- A_V must account for Non-Photosynthetic Vegetation (NPV)

Table 2: **Erodibility Responses of Major Dust Source Regions**[a]

Region	P, τ	P, N	N, τ	P, U	U, τ	Cat.[b]
Eastern Sahel	$-0.27(9)$	$+0.33(1)$	$-0.31(0)$			I
Bodélé Depression	$-0.28(9)$	$+0.26(9)$	$-0.31(0)$			I
Western US	$-0.22(0)$	$+0.47(1)$	$-0.35(0)$			I
Lake Eyre Basin	$-0.36(1)$	$+0.61(1)$	$-0.29(1)$			I
Botswana	$-0.39(1)$, $-0.23(0)$	$+0.56(2)$, $+0.31(0)$	$-0.28(9)$			I
Gobi Desert			$-0.28(2)$			I
China Loess Plateau	$-0.27(0)$					II
Great Salt Lake	$-0.37(0)$	$-0.27(0)$		$+0.26(0)$		II
Zone of Chotts	$+0.21(44)$	$+0.42(26)$		$+0.26(0)$		III
Tigris/Euphrates	$+0.21(14)$	$-0.26(8)$				III
Saudi Arabia	$+0.36(0)$	$-0.27(0)$				IV
Oman	$+0.40(0)$					IV
Tarim Basin			$+0.28(21)$		$+0.23(0)$, $-0.24(2)$	IV
Thar Desert	$+0.25(0)$, $-0.24(1)$, $-0.21(2)$	$+0.57(1)$	$-0.3(0)$, $-0.33(10)$	$-0.35(0)$	$+0.3(1)$	I, IV

[a] Highly significant ($p < 0.01$) cross-correlations r between autoregression-corrected erodibility indicators (dust AOD τ) and climate constraints (precipitation P, NDVI N, and wind speed U) from 1979–1994. Lag in months of indicated cross-correlation is shown in parentheses.

[b] Erodibility Category Assigned

Table 3: **Erodibility Categories of Major Dust Source Regions**

Cat.	Response[a]	Regions
I	$P \downarrow \tau, P \uparrow N, N \downarrow \tau$ Strong moisture and vegetation constraints, multiple timescales	Eastern Sahel, Bodélé Depression, Western US, Lake Eyre, Botswana, Thar Desert (Gobi Desert)
II	$P \downarrow \tau$ Strong moisture constraints, immediate response	China Loess Plateau, Great Salt Lake
III	$P \uparrow \tau$ Supply-limited, interannual alluvial recharge?	Zone of Chotts, Tigris/Euphrates
IV	$P \uparrow \tau$ Supply-limited, crustal (de-)formation	Saudi Arabia, Oman, Tarim Basin, Thar Desert

[a]Positive and negative correlations indicated by $\uparrow$ and $\downarrow$, respectively

4. Production-Oriented Observations

Improving understanding and representation of production processes requires coordinated Production-Oriented Observations (POO).

- Saltation-sandblasting (SS) dust production models (DPMs) require *aggregate* surface soil particle size distribution as inputs.
  - SS (minimally) depends on $n_{\mathrm{n}}(D)$ for $70 < D < 1000$ [1]
  - SS may require dis-aggregated $n_{\mathrm{n}}(D)$ (Y. Shao)
  - How to observe $n_{\mathrm{n}}(D)$ in active regions?
- Evaluating DPM predictions of SS begins with evaluating saltation flux Q_{s}.
  - How to observe Q_{s} in active regions?

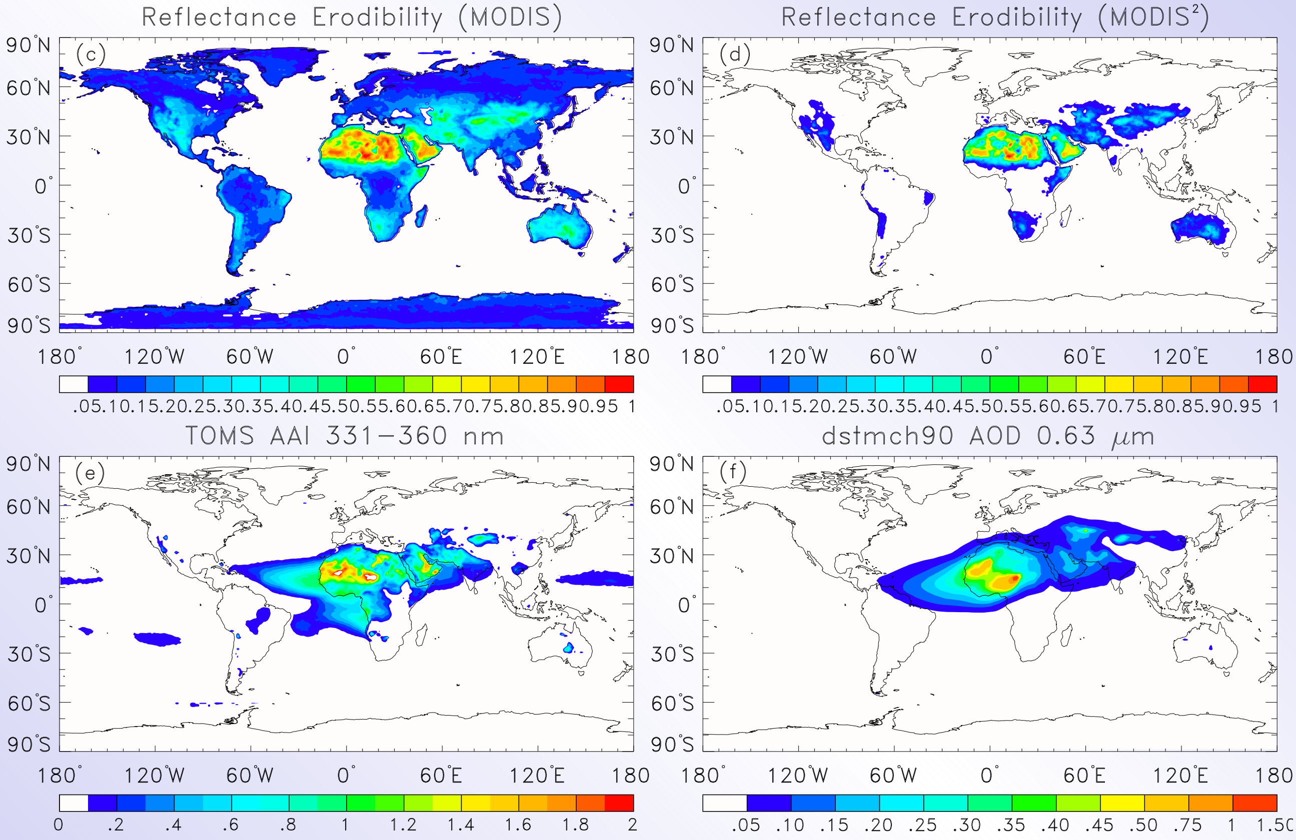


Figure 1: Erodibility factors predicted by two Reflectance-based methods: (c) Linear and (d) quadratic with MODIS surface reflectance [2]. Aerosol distribution from (e) TOMS Absorbing Aerosol Index (1980–2001) [3]. Simulated dust optical depth at 0.63 μm [10]. Note differences in scales.

- Spectral and broadband surface reflectance correlates well with FAO soil type [9]
  - Dunes/Shifting Sands have very high albedo
  - Salty playas have high albedo
  - Rocky soils have low albedo
- Broadband MODIS surface reflectance proves a good erodibility indicator [2]
  - $\mathcal{R}$ is better erodibility proxy in Africa than East Asia
  - Needs more work…
- Retrieve aggregate size distribution for DPM from $\mathcal{R}$?
  - Spectral surface reflectance sensitive to aggregate particle size distribution to within $\sim 100\,\mu\mathrm{m}$ [5]
  - Likely requires regional mineral composition and ground truth

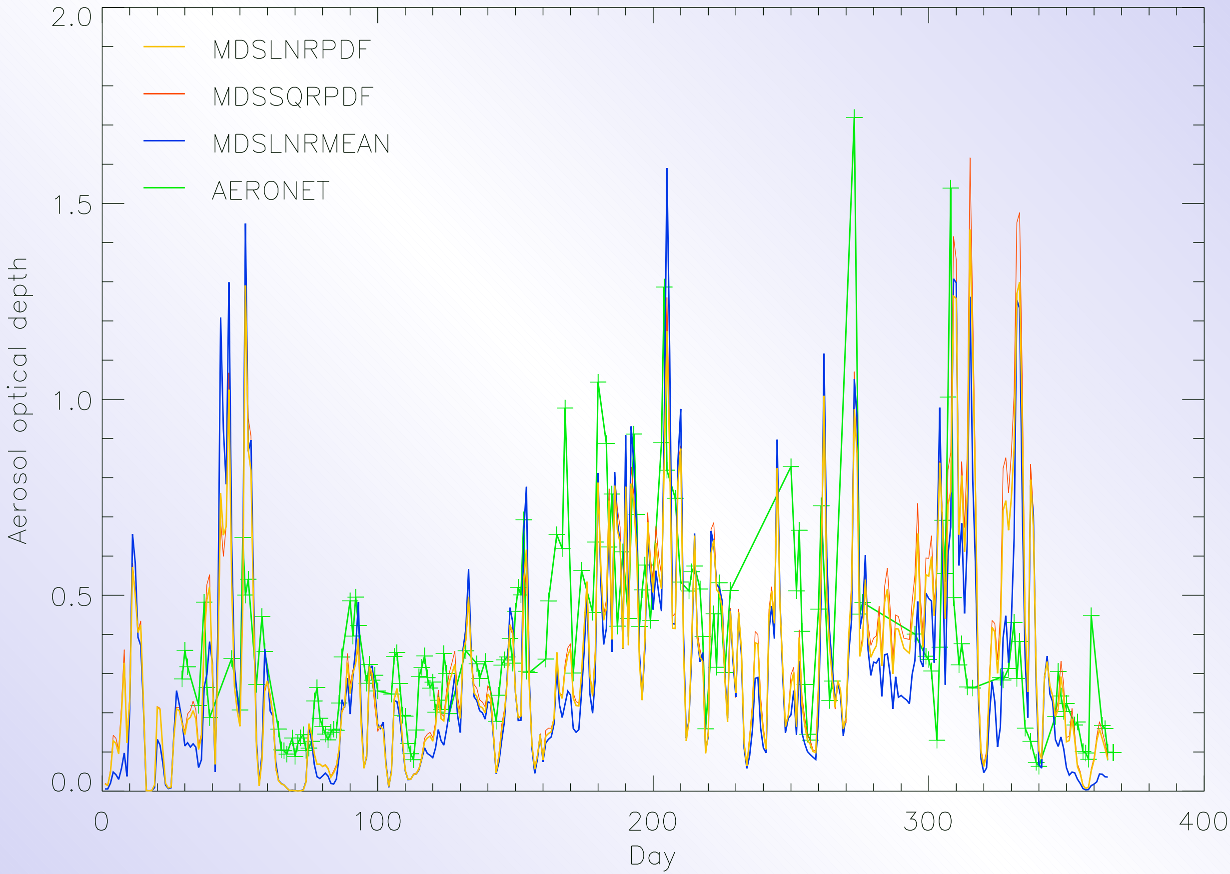


Figure 2: 1996 Aerosol Optical Depth (AOD) at Cape Verde from AERONET and three reflectance-based simulations, MDSLNRPDF, MDSSQRPDF and MDSLNRMEAN.

5. Loess Observations

Predicting dust response to climate change easy to do and hard to do right.

- Is model erosion sensitivity to climate change too high or low?
- Sediment records are far from source regions (DIRTMAP, ice cores)
- Loess deposits near source regions may provide production proxy

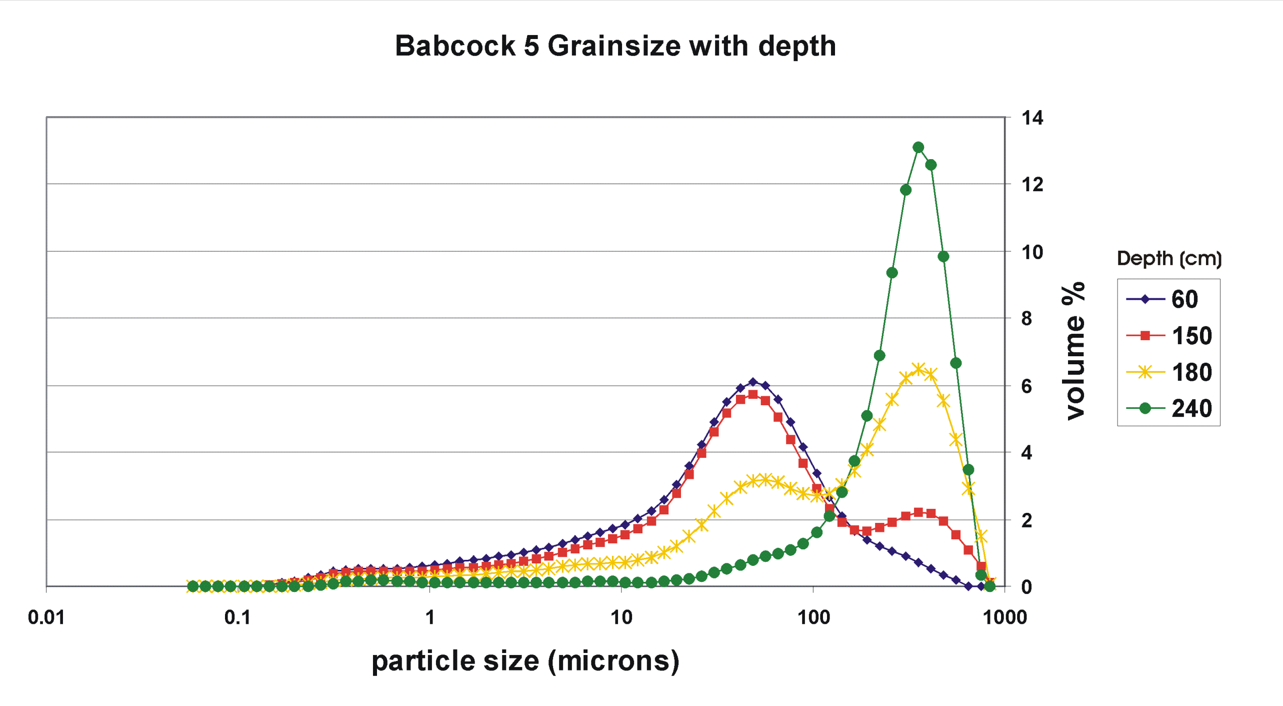


Figure 3: (a) Vertical profile of loess size distribution from Columbia Plateau (*Figure*: M. Sweeney, Washington State University).

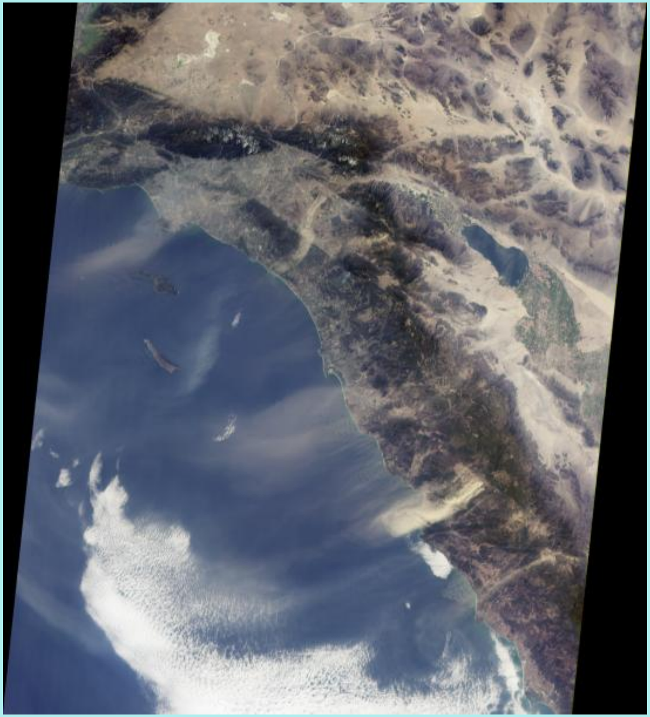
- WSU (Busacca, Gaylord, and Sweeney) re-constructing ~ 18 ka of MARs. UCI (Zender) fitting MARs to dust emissions. (NSF ATM-0214430)

6. Evaluating DPMs with Loess Observations

- Adapting DPMs to predict loess sizes provide opportunity to compare again loess record near source regions
  - Obtaining loess Mass Accumulation Rates (MARs) difficult
  - Mass Accumulation Rates (MARs) and $n_{\mathrm{n}}(D)$ record a convoluted climate, production, transport, deposition signal [6, 7, 8]
  - Global model could evaluate predicted against observed ΔMARs under climate change scenarios
  - Obtaining paleo-vegetation, winds, etc., is very difficult

7. Sensor Network

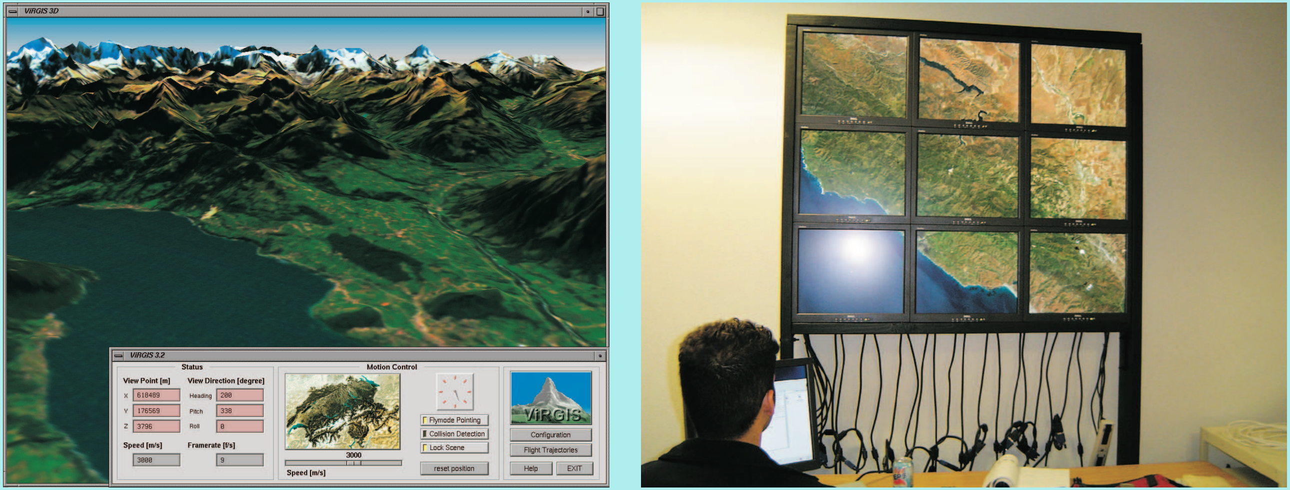
- Could propose a dust Integrated Sensor Network (ISN) (e.g., SCCOOS, SCAQMD) in Region of Interest (RoI)
- Deploy dozens (anememoters) to hundreds (sensits) of sensors in RoI
  - Sensits are saltation sensors which measure impacts per second and impact kinetic energy.
  - USGS has had three instrumented stations with Sensits and anemometers in Mojave since 1999
    - Can inexpensive, tough, biodegradable Sensits be built?
- Missing ingredients:
  - Surface size distribution
  - Non-Photosynthetic vegetation (NPV) (remotely sensed?)
  - Surface crusting (penetrometer or remotely sensed proxy)?
- ISN would be most useful with dedicated facility



Santa Ana-driven Mojave Dust, February 2002.
(*Figure*: NASA SeaWiFS)

Ingredients for Integrated Sensor Network:

1. Detailed mapping of RoI
2. Sensor station development, deployment, maintenance
3. Fully coupled mesoscale model & simulations
4. Civil Expertise (e.g., BLM, CDHS, NPS, SCAQMD, USGS)
5. Scientific guidance
6. ITR?



a) b)

Figure 4: (a) Example interactive environmental exploration. (b) Synchronized distributed rendering on tiled-display wall. (*Figure*: R. Pajarola).

- UCI Earth System Modeling Facility (ESMF) [12] with a HIPerWall (180 MP tiled display) [4] for visualization
- Integrate sensors, mesoscale models, and interactive forecasts to create a Lab. for Environmental Planning (LEP) [11]

8. References

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